



Diversity of organisms

Revision notes • IB Biology A3.1: variation, species concepts, binomial names, chromosome numbers, karyograms, genome diversity and whole genome sequencing.

For IB Diploma Biology, Standard Level and Higher Level (first assessment 2025). **HL only** is additional higher level content, for HL students only.

Diversity of organisms Spec A3.1

Variation, species and binomial names Spec A3.1.1, A3.1.2, A3.1.3

Variation between organisms is a defining feature of life. No two individuals are identical in all their traits, even identical twins or clones differ slightly. The patterns of variation are complex, and they are the basis for naming and classifying organisms.

Some differences are small and found within a group (eye colour in humans). Others are large and consistent and separate one group from another (the number of legs in insects and spiders). Biologists use these consistent patterns to recognise species.

Species as groups with shared traits

The original idea of a species, used by Linnaeus in the 18th century, was **morphological**: a species is a group of organisms with shared traits. Organisms that look alike in their structure (morphology) are placed in the same species, and organisms with consistently different traits are placed in different species.

This works well for many organisms, but appearance can mislead. Males and females of one species can look very different, and different species can look almost identical.

The binomial system

Every species has a two-part scientific name, its **binomial**. The first part identifies the **genus**. The second part distinguishes the **species** within that genus. Species in the same genus have similar traits.

- The genus name has an initial capital letter; the species name is all lowercase: *Homo sapiens*, *Pan troglodytes*.
- Binomials are printed in italics or underlined when handwritten.
- After first use, the genus can be shortened to its initial: *H. sapiens*.
- Binomials are international, so scientists everywhere know exactly which organism is meant, whatever its local common name.

Two species in the genus *Panthera*

Binomial	Common name	Genus	Species name
<i>Panthera leo</i>	lion	<i>Panthera</i>	<i>leo</i>
<i>Panthera tigris</i>	tiger	<i>Panthera</i>	<i>tigris</i>

Common mistake: Writing *homo Sapiens* or *Homo Sapiens* loses the mark. Only the genus has a capital letter.

Exam tip: Linking question: how do species show both continuous and discontinuous variation? Traits vary continuously within a species, yet species themselves are discrete groups.

The biological species concept and speciation Spec A3.1.4, A3.1.5

Biological species concept	A species is a group of organisms that can breed and produce fertile offspring.
Population	A group of organisms of the same species living in the same area at the same time.
Speciation	The splitting of one species into two or more.

The biological species concept focuses on **interbreeding** rather than appearance. A horse and a donkey can mate, but their offspring, the mule, is **infertile**, so horses and donkeys are separate species.

Challenges to the biological species concept

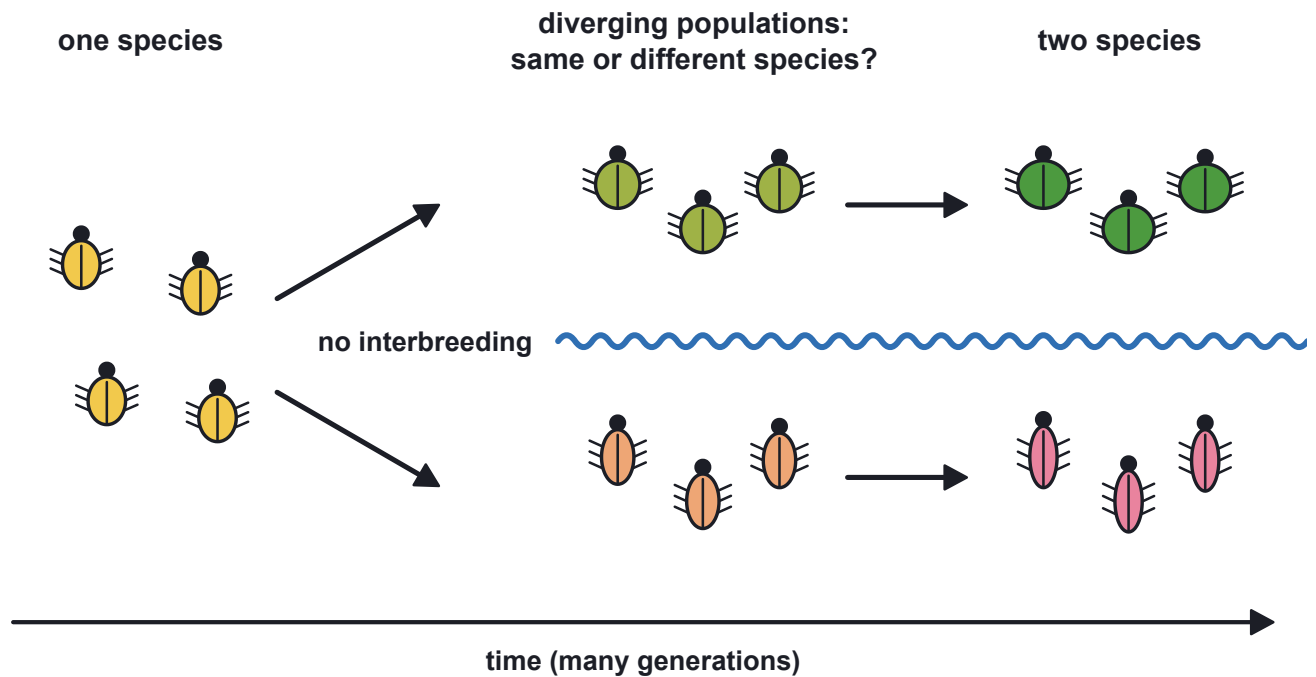
- Extinct organisms known only from fossils cannot be tested for interbreeding.
- Populations that are geographically separated never meet, so it is not known whether they would interbreed in the wild.
- Some organisms reproduce asexually, so interbreeding does not apply to them.
- Some closely related species occasionally produce fertile hybrids.
- Testing interbreeding in captivity may not reflect what happens in the wild.

Because of these problems, **competing species definitions** exist. Examples include the morphological concept (shared traits), an ecological concept (a shared niche) and a phylogenetic concept (a group sharing a unique common ancestry, often judged from DNA sequences). Biologists choose the concept that suits the organisms they study.

Why populations and species are hard to tell apart

Speciation usually happens **gradually** rather than by a single act. When populations stop interbreeding, each one changes independently, so they become more and more different in their traits. There is no clear moment when two populations become two species.

At an intermediate stage, populations may be partly different, with some interbreeding still possible. It can therefore be an **arbitrary** decision whether two populations are regarded as the same species or different species.



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Speciation is **gradual**: once populations stop interbreeding they diverge, and there is no clear moment when they become **two species**.

Chromosome numbers and karyograms Spec A3.1.6, A3.1.7

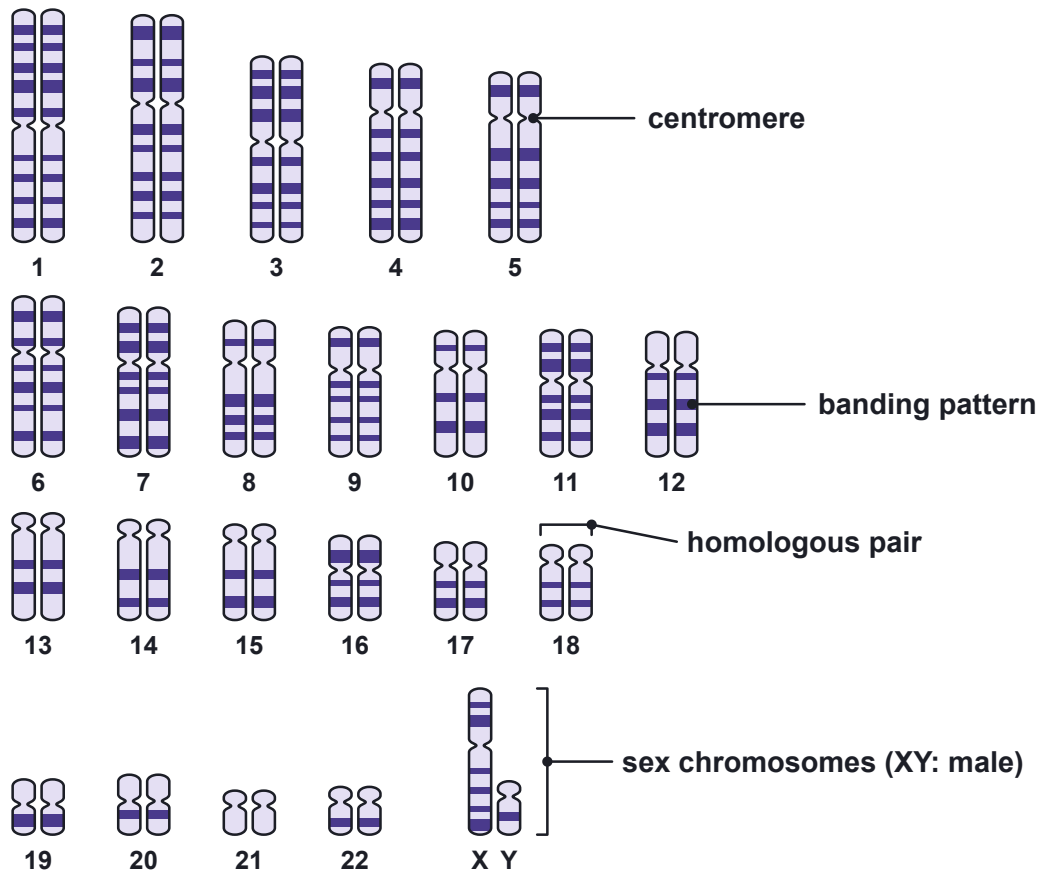
Plant and animal species show great **diversity in chromosome number**. Humans have **46** chromosomes and chimpanzees have **48**. Diploid cells normally have an **even number**, because their chromosomes are in homologous pairs, one from each parent.

Karyotype	The number and type of chromosomes present in the nucleus of a cell of an organism.
Karyogram	An image of the chromosomes of a cell arranged in homologous pairs, in order of decreasing length.
Centromere	The region where the two sister chromatids are held together; its position along the chromosome is used to identify chromosomes.

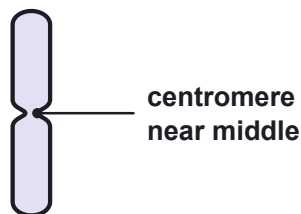
Making a karyogram

1. Take cells that are dividing and stop them in metaphase of mitosis, when chromosomes are most condensed.
2. Spread the chromosomes on a slide and stain them, which gives each chromosome a pattern of light and dark bands.
3. Photograph the chromosomes under a microscope.
4. Pair up homologous chromosomes and arrange the pairs by length, longest first, with the sex chromosomes last.

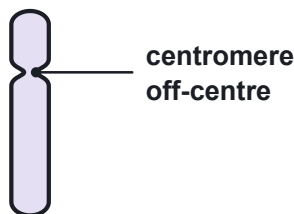
Chromosomes are classified by three features: **length**, **centromere position** (near the middle, off-centre or near one end) and **banding pattern**. A karyogram shows the sex of the individual (XX or XY) and any unusual chromosome number, such as three copies of chromosome 21.



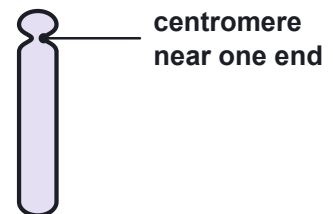
centromere position



centromere
near middle



centromere
off-centre



centromere
near one end

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A male karyogram (XY): homologous pairs arranged by **length**, **centromere position** and **banding pattern** (bands drawn schematically).

The chromosome 2 fusion hypothesis

Humans and chimpanzees share a common primate ancestor. The hypothesis is that human **chromosome 2** arose from the end-to-end **fusion** of two chromosomes inherited from that shared ancestor. These two chromosomes are still separate in chimpanzees: the IB guide calls them chromosomes 12 and 13, from an older numbering, and today they are usually called chromosomes 2A and 2B. The fusion happened in the human lineage after it split from the chimpanzee lineage, and it reduced the diploid number from 48 to 46. The evidence:

- The banding pattern of human chromosome 2 matches that of chimpanzee chromosomes 12 and 13 (2A and 2B) placed end to end.
- Telomere sequences, normally found only at chromosome ends, occur near the middle of human chromosome 2, at the proposed fusion point.

- Human chromosome 2 has remains of a second, inactive centromere, in the position expected for the centromere of the second ancestral chromosome.
- Genes on human chromosome 2 are largely in the same order as on the two chimpanzee chromosomes.

The evidence strongly supports the hypothesis but the fusion itself was never observed. The match is not perfect in every detail, because each lineage has had some smaller chromosome changes, such as inversions, since the split.

Practical skill: When classifying chromosomes in a karyogram, compare length first, then centromere position, then banding pattern. When evaluating the fusion hypothesis, say what each piece of evidence predicts and whether it is observed.

Exam tip: Nature of science: the origin of chromosome 2 is a testable hypothesis, because it makes predictions (telomere sequences mid-chromosome, a second centromere) that could have been shown false. A statement that makes no testable prediction is not scientific.

Unity and diversity of genomes Spec A3.1.8, A3.1.9, A3.1.10

Genome	All the genetic information of an organism.
Single-nucleotide polymorphism (SNP)	A position in the base sequence of a gene or genome where individuals of a species differ in a single base.
Genome size	The total amount of DNA in one set of an organism's chromosomes, usually given in base pairs.

Unity and diversity within a species

Organisms in the same species **share most of their genome**: they have the same genes in the same order on the same chromosomes. This is the unity. Diversity comes from small differences in base sequence, mainly **single-nucleotide polymorphisms** (SNPs). Different versions of a gene (alleles) often differ in only one or a few bases. Any two humans have about 99.9% of their base sequence in common.

Diversity of eukaryote genomes

- Genomes vary in **overall size**, which is determined by the total amount of DNA.
- Genomes vary in **base sequence**, including which genes are present.
- Variation **between species** is much larger than variation within a species.

Comparing genome sizes

Approximate haploid (1C) genome sizes, rounded, from genome databases such as NCBI Genome and the Plant DNA C-values database		
Organism	Group	Genome size / million base pairs
<i>Escherichia coli</i>	bacterium (prokaryote, for comparison)	4.6
<i>Saccharomyces cerevisiae</i> (yeast)	fungus	12
<i>Arabidopsis thaliana</i>	flowering plant	135
<i>Drosophila melanogaster</i> (fruit fly)	insect	180
<i>Homo sapiens</i> (human)	mammal	3,100
<i>Triticum aestivum</i> (bread wheat)	flowering plant	16,000
<i>Paris japonica</i>	flowering plant	149,000

Very simple organisms tend to have small genomes, but there is **no close correlation between genome size and complexity**. Some plants have genomes many times larger than the human genome. Much of a large genome is non-coding DNA, including repeated sequences, rather than extra genes. Some plants, including bread wheat and *Paris japonica*, are also polyploid, with several whole sets of chromosomes in each nucleus.

Comparing genome sizes

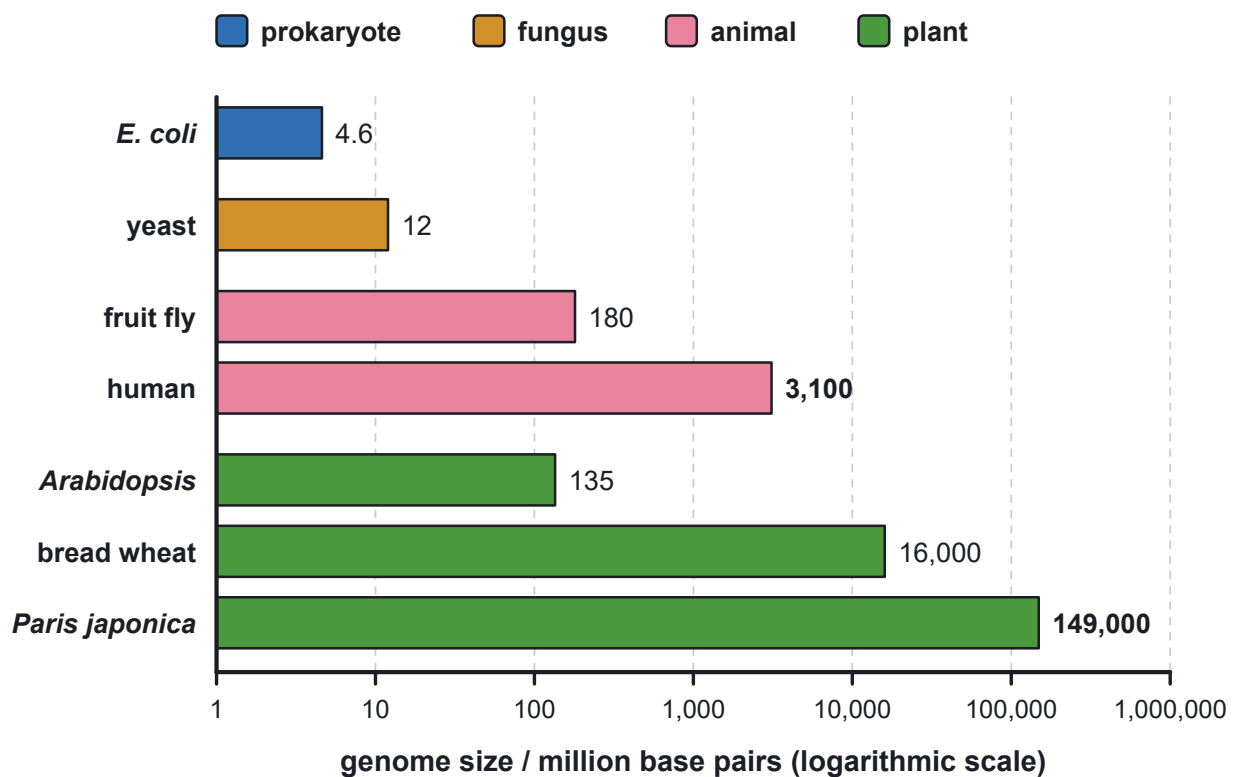
Using the table, calculate how many times larger the genome of bread wheat is than the human genome.

1. Ratio = wheat genome size ÷ human genome size

2. = 16,000 ÷ 3,100

3. = 5.16

Answer: The wheat genome is about 5.2 times larger than the human genome.



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Genome sizes from the table on a **logarithmic scale**: *Paris japonica* has about 50 times more DNA than a human, so size does **not** track complexity.

Practical skill: Tools: genome sizes span many orders of magnitude, so plot them on a logarithmic scale. When extracting data from a database, record the source and use the same measure (haploid size in base pairs) for every organism.

Whole genome sequencing Spec A3.1.11

Whole genome sequencing means determining the complete base sequence of all the DNA of an organism. The Human Genome Project produced the first human genome sequence, completed in 2003 after about 13 years and at a cost of billions of US dollars.

Since then, automated high-throughput sequencers have given **increasing speed and decreasing costs**. A human genome can now be sequenced in around a day for roughly a thousand US dollars or less. This

means thousands of genomes, from many individuals and species, can be compared.

Uses of whole genome sequencing	
Use	What it involves
Current: research into evolutionary relationships	Comparing whole genomes of different species shows how many base differences separate them, which indicates how closely related they are and when they shared a common ancestor.
Current: research into variation within species	Sequencing many individuals reveals SNPs and links some of them to traits or diseases.
Potential future: personalised medicine	A patient's own genome could be used to predict disease risk and to choose the drugs and doses that work best for that person.

Personalised medicine raises issues too: genome data is personal, and knowing a genetic risk can affect insurance, employment and family members.

Exam tip: For whole genome sequencing, the guide expects three points: speed up and cost down, evolutionary relationships as a current use, and personalised medicine as a possible future use.

Limits of the biological species concept Spec A3.1.12, A3.1.13 HL only

Asexual reproduction

The biological species concept depends on **interbreeding**. Organisms that reproduce only **asexually** produce offspring from a single parent, so there is no interbreeding to test. Every individual is reproductively isolated, so by this definition each clone could count as a separate species, which is not useful.

Bacteria and horizontal gene transfer

Bacteria reproduce asexually by binary fission. They can also gain genes from other bacteria, even of other species, by **horizontal gene transfer**: for example plasmids passed from cell to cell. Genes therefore move between groups that the concept would treat as separate species, so the boundaries between bacterial species are blurred. Bacterial species are usually defined by similarity of base sequences instead.

Chromosome number as a shared trait

Members of a species have the **same chromosome number**. Cross-breeding between closely related species is **unlikely to produce fertile offspring** if the parents have different chromosome numbers.

- A horse (64 chromosomes) and a donkey (62) can produce a mule, with 63 chromosomes.
- In meiosis, the mule's chromosomes cannot all form homologous pairs, so meiosis fails and few or no viable gametes form.
- The mule is therefore infertile, which confirms that horses and donkeys are different species.

Exam tip: Linking question: what might cause a species to persist or go extinct? Reproductive isolation, such as a difference in chromosome number, keeps a species' gene pool separate.

Dichotomous keys and environmental DNA Spec A3.1.14, A3.1.15 HL only

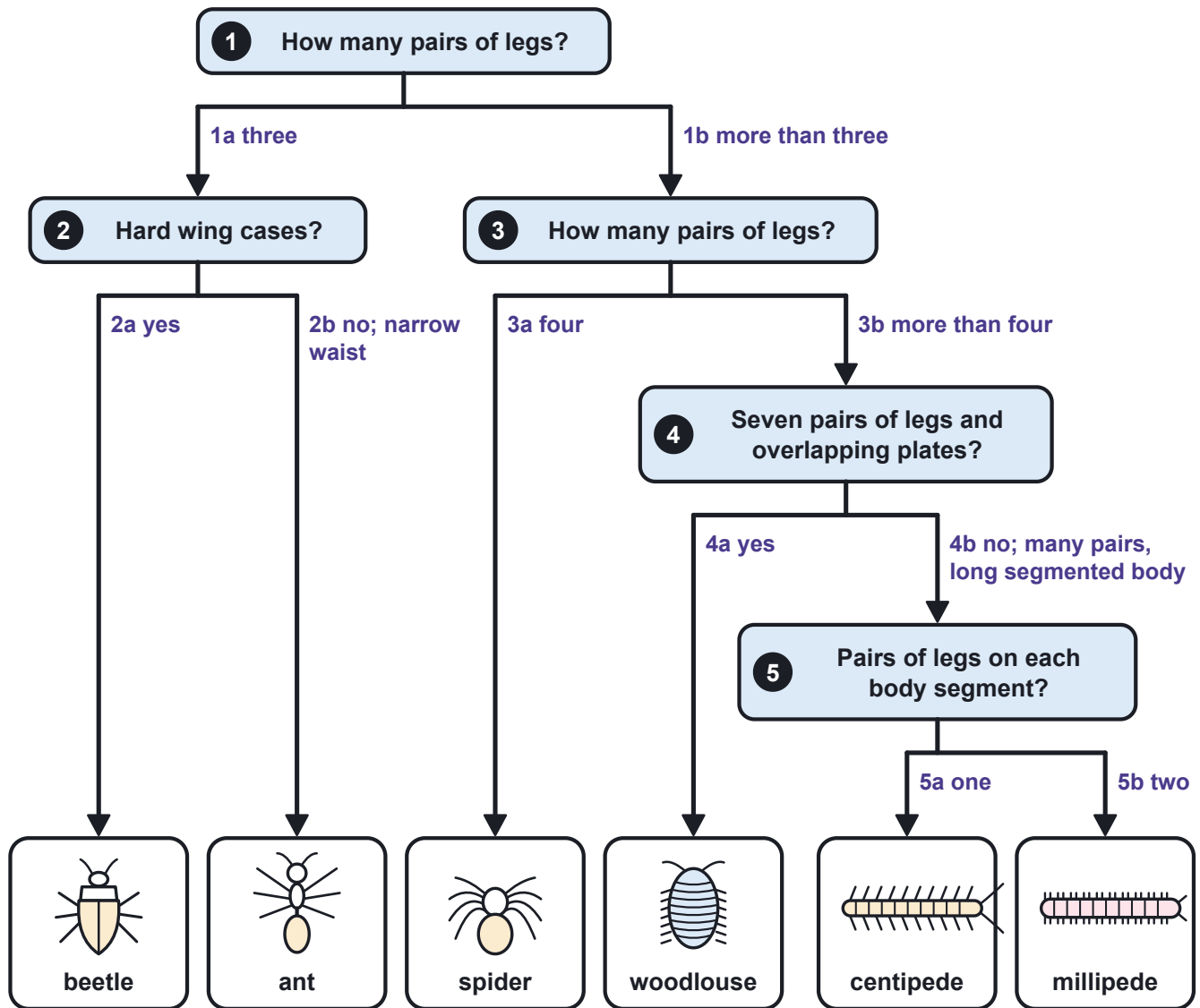
Dichotomous keys

A **dichotomous key** is a series of numbered steps, each with **two contrasting descriptions**. Choosing the description that fits leads either to another step or to the name of the organism.

A key to common invertebrates found in leaf litter

Step	Description	Go to
1a	Three pairs of legs	2
1b	More than three pairs of legs	3
2a	Hard wing cases covering the abdomen	beetle
2b	No wing cases; narrow waist between thorax and abdomen	ant
3a	Four pairs of legs	spider
3b	More than four pairs of legs	4
4a	Seven pairs of legs; body covered by overlapping plates	woodlouse
4b	Many pairs of legs; long, segmented body	5
5a	One pair of legs on each body segment	centipede
5b	Two pairs of legs on each body segment	millipede

Practical skill: Build your key from local species you can observe. Use features that are easy to see and do not vary within a species, such as leg number or leaf arrangement, not size or colour. Test the key on specimens and revise any step that gives the wrong name.



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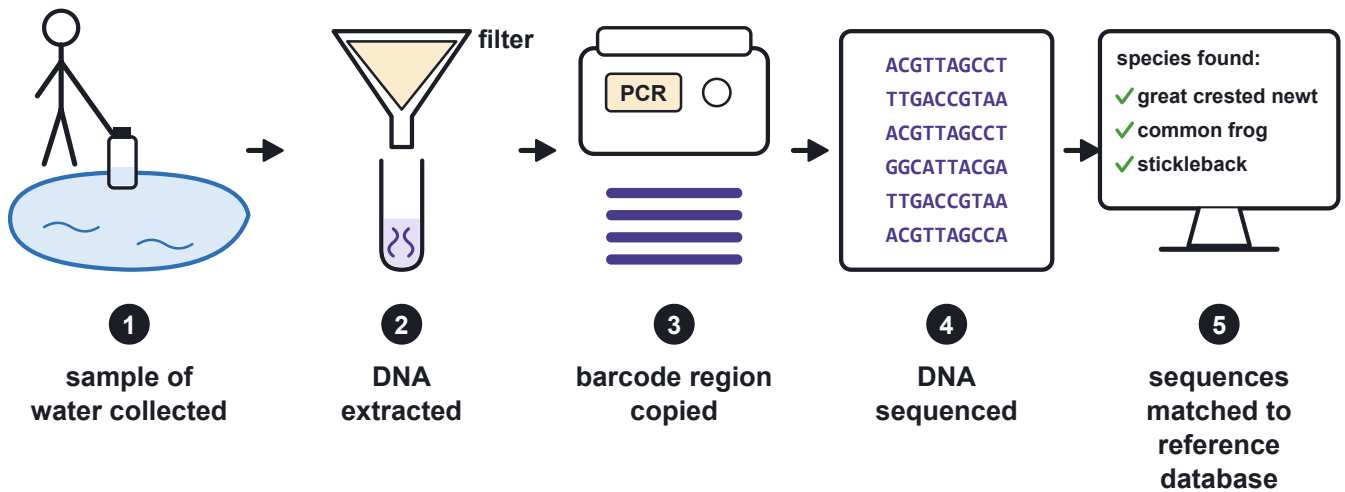
The leaf-litter key as a flow chart: each numbered step has **two contrasting choices**.

Environmental DNA and barcodes

Organisms constantly shed cells, mucus, faeces and gametes, so soil and water contain their DNA. This is **environmental DNA** (eDNA). A **DNA barcode** is a short, standard section of the genome that differs between species, for example part of a mitochondrial gene in animals or a chloroplast gene in plants.

1. Collect a sample of water, soil or sediment from the habitat.
2. Extract the DNA from the sample.
3. Copy the barcode region by PCR, using primers that bind to sequences shared by a whole group of organisms.
4. Sequence the copied DNA.
5. Compare each sequence with a reference database of barcodes from identified species to find which species are present.

Using barcodes and eDNA allows the **biodiversity of habitats to be investigated rapidly**. It can detect rare, hidden or microscopic species without catching or even seeing them, for example great crested newts in a pond from a water sample. Limits: a species can only be named if its barcode is in the database, and DNA can drift in from elsewhere or persist after the organism has gone.



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Using **eDNA** and barcodes: sample, extract, copy by PCR, sequence, then match to a **reference database**.

Quick check

1. In a binomial, which part has a capital letter?
2. State the biological species concept.
3. How many chromosomes do humans and chimpanzees have?
4. What is a genome?
5. **HL only** Why is a mule infertile?

Quick check answers

Diversity of organisms

1. The genus name (first part). The species name is all lowercase.
2. A species is a group of organisms that can breed and produce fertile offspring.
3. Humans 46, chimpanzees 48.
4. All the genetic information of an organism.
5. Its parents have different chromosome numbers, so its chromosomes cannot all pair in meiosis and viable gametes are not produced.